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Final Technical Report

"Measurements of Turbulent Wall Eddies with Selective Suction"
(ASSERT)
(N00014-92-J-1062)

10/01/91 to 02/28/96

by

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Description of the Scientific Research Goals

This investigation was designed to aid the underlying research contract by providing flow visualization of the flow actuators used to control streamwise vortices in the wall region of a bounded shear flow.

Significant Results

The flow visualizations were performed in the USC Water Channel on a flat plate. The test section is 6m long and has a cross section of .6m x .9m. The turbulence intensity is less than 0.1% and provides an excellent test bed for transition and turbulent studies. The results have illustrated a different mechanism for producing low speed regions and streamwise vortices near the wall. The experimental setup was similar to that used in the wind tunnel in the associated report. Fixed and active delta wing actuators were used. They were scaled to the flow parameters in the laminar boundary layer in the water channel. The non-dimensional frequencies were similar to those used in the wind tunnel. However when the actuators were implemented, vortices of the opposite sign and an order of magnitude larger than expected were generated as discussed below.

Vortex generators consisting of small fixed delta wings with amplitudes of typically a quarter of the boundary layer thickness were placed on the wall of the water channel. When a delta wing had its apex pointed upstream, the two vortices which were produced had a down-flow between them. The visualization showed that these vortices were very stable and the vortices persisted for great distances(typically a hundred boundary layer thickness) downstream. This resulted from the mutual interaction of the vortices; i.e. the induced flow causes them to move apart from each other in the spanwise direction thus decreasing their interaction. On the other hand, when a delta wing was placed into the flow field with its apex pointed downstream, the two counter-rotating vortices which are produced have a mutual interaction that attracts them to each other and they interact. This produces

an up-flow between them; i.e. the normal velocity is positive between the two vortices, and they move away from the wall. These vortices were very unstable and persisted only a few boundary layer thickness downstream. Consequentially, when fixed delta wings are used as vortex generators, they should be designed with the above results in mind.

When the piezo-ceramic delta wings were flush mounted on the wall and oscillated, a completely different phenomena was observed which illuminated how the actuators are able to delay the transition. Initially it was assumed that the oscillating delta wing would produce unsteady vortices that would counteract the existing streamwise Görtler vortices. However it was discovered that when the actuator was orientated to produce such vortices, the transition was hastened. The visualization indicated the reason. First, since very small amplitudes(i.e. of the order of υ/u_τ)produced large effects, the delta wings were operating in a strongly viscous region and hence no discernable vortices were produced. Instead the high frequency oscillations of the delta wing(which is approximately parallel to the wall) produced a streaming flow parallel to the wall. The actual direction depended upon the geometry of the actuator. For the delta wing, a strong spanwise component was evident. This component created a spanwise streaming flow very near the wall that moved in the spanwise direction until slowed by viscosity. This displaced fluid accumulated at a fixed spanwise location depending upon the frequency, amplitude and geometry of the actuator. As more fluid was displaced in the spanwise direction, the accumulated fluid moved upward and convection carried it downstream. With continued oscillation, the net result was a new region of low speed fluid which corresponded to a large scale steady pair of counter-rotating vortices. However, their sense of rotation was opposite to the steady state vortices discussed above. This region was 180° out of phase from where it would be expected if the wing were shedding streamwise vortices.

This phenomena disclosed a new method of generating streamwise vortices that may have several advantages. First, when the device was not in use, it was flush with the wall with no protrusions. Secondly, to generate a low speed region comparable to that produced by a fixed delta wing required an amplitude at the apex of the delta wing an order of magnitude lower than the amplitude of the steady state delta wing described above. Thirdly, the lower amplitude implied that the device drag should be much lower than the device drag of the steady state vortex. Although the drag produced by these devices has not yet been measured, it is expected to be significantly lower than that of the steady state delta wing because their amplitudes are an order of magnitude smaller. Fourthly, they produce a significant spanwise velocity at the wall which could be significant in reducing the drag in turbulent bounded flows as has been demonstrated in the literature(i.e. Choi et al, JFM, **262**, 75, 1994).